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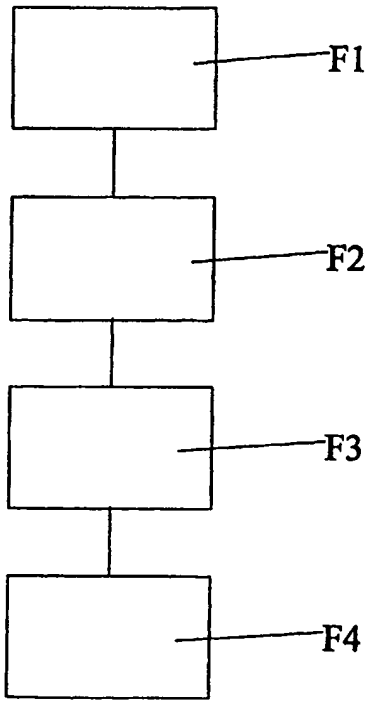
(54) Title: DYNAMIC TAXONOMY PROCESS FOR BROWSING AND RETRIEVING INFORMATION IN LARGE HETEROGENEOUS DATA BASES

(57) Abstract

A process is disclosed for retrieving information in large heterogeneous data bases, wherein information retrieval through visual querying/browsing is supported by dynamic taxonomies; the process comprises the steps of: initially showing (F1) a complete taxonomy for the retrieval; refining (F2) the retrieval through a selection of subsets of interest, where the refining is performed by selecting concepts in the taxonomy and combining them through Boolean operations; showing (F3) a reduced taxonomy for the selected set; and further refining (F4) the retrieval through an iterative execution of the refining and showing steps.



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DYNAMIC TAXONOMY PROCESS FOR BROWSING AND RETRIEVING INFORMATION IN LARGE HETEROGENEOUS DATA BASES

The present invention refers to a dynamic taxonomy process for browsing and retrieving information in large heterogeneous data bases.

Information retrieval on this type of data bases (for example those available on the Internet) is nowadays a slow task, sometimes impossible to realize due to the enormous amount of data to be analyzed, and that can be implemented with difficulty with the currently available tools. The present Applicants developed for such purpose a process solving the above problems by an innovative use of taxonomies as a structuring and information access tool.

Dynamic taxonomies are a model to conceptually describe and access large heterogeneous information bases composed of texts, data, images and other multimedia documents.

A dynamic taxonomy is basically a IS-A hierarchy of concepts, going from the most general (topmost) to the most specific. A concept may have several fathers. This is a conceptual schema of the information base, i.e. the "intension". Documents can be freely classified under different concepts at different level of abstraction (this is the "extension"). A specific document is generally classified under several concepts.

Dynamic taxonomies enforce the IS-A relationship by containment, i.e. the documents classified under a concept C are the deep extension of C, i.e. the recursive union of all the documents classified under C and under each descendant C' of C.

In a dynamic taxonomy, concepts can be composed through classical boolean operations. In addition, any set S of documents in the universe of discourse U (defined as the set of all documents classified in the taxonomy) can be represented by a reduced taxonomy. S may be synthesized either by boolean expressions on concepts or by any other retrieval method (e.g. "information retrieval"). The reduced taxonomy is derived from the original

taxonomy by pruning the concepts (nodes) under which no document d in S is classified.

A new visual query/browsing approach is supported by dynamic taxonomies. The user is initially presented with the complete taxonomy. He/she can then refine the result by selecting a subset of interest. Refinement is done by selecting concepts in the taxonomy and combining them through boolean operations. She/he will then be presented with a reduced taxonomy for the selected set of documents, which can be iteratively further refined.

The invention described here covers the following aspects of dynamic taxonomies:

1. additional operations;
2. abstract storage structures and operations on such structures for the intension and the extension;
3. physical storage structures, architecture and implementation of operations;
4. definition, use and implementation of virtual concepts;
5. definition, use and implementation of time-varying concepts;
6. binding a dynamic taxonomy to a database system;

7. using dynamic taxonomies to represent user profiles of interest and implementation of user alert for new interesting documents based on such profiles of interest.

The above and other objects and advantages of the invention, as will appear from the following description, are obtained by a dynamic taxonomy process as claimed in Claim 1. Preferred embodiments and non-trivial variations of the present invention are claimed in the dependent Claims.

The present invention will be better described by some preferred embodiments thereof, given as a non-limiting example, with reference to the enclosed drawing, whose Fig. 1 shows a block diagram of the process of the present invention.

Before proceeding with a detailed description of the invention, suitable terminology remarks will be made. The set of documents classified under the taxonomy (corpus) is denoted by U, the universe of discourse. Each document d in U is uniquely identified by an abstract label called document ID of d (DID(d)). Each concept c in the taxonomy is uniquely identified by an abstract label called concept ID of c (CID(c)). Concepts are partitioned

into terminal concepts (concepts with no concept son in the taxonomy) and non-terminal concepts. T denotes the set of concepts used in the taxonomy.

The taxonomy is usually a tree, but lattices (deriving from a concept having more than one father) are allowed. Documents can be classified under any (terminal or non-terminal) concept in the taxonomy. A specific document d in U may be classified under one or more concepts. The single, most general concept in the taxonomy is called the root of the taxonomy. This concept need not be usually stored in the extension, since it represents the entire corpus.

The term "deep extension" of a concept c denotes all the documents classified under c or under any descendant of c. The term "shallow extension" of a concept c denotes all the documents directly classified under c.

If c is a concept, $C^{up}(c)$ denotes the set {c union {c': c' is an ancestor of c in the taxonomy, and c' is not the root of the taxonomy}}. $C^{up}(c)$ is computed by the recursive application of operation AIO3 (described hereinbelow). If c is a concept, $C^{down}(c)$ denotes the set {c union {c': c' is a descendant of c in the taxonomy}}. $C^{down}(c)$ is

computed by the recursive application of operation AIO2 (described hereinbelow).

With reference to Fig. 1, a block diagram is shown of the main steps of the process of the present invention, from which all further developments of the process itself originate, such developments being described hereinbelow.

According to the diagram in Fig. 1, the process for retrieving information on large heterogeneous data bases of the present invention comprises the steps of:

(F1) initially showing a complete taxonomy for retrieval;

(F2) refining the retrieval through a selection of subsets of interest, where the refining step is performed by selecting concepts in the taxonomy and combining them through boolean operations;

(F3) showing a reduced taxonomy for the selected set; and

(F4) further refining the retrieval through an iterative execution of the refining and showing steps.

In addition to the previously-described operations, the following operations can be supported:

a. projection under a given CID of a set S of DIDs: it extracts all the children c of CID such as there is at least a document in S in the deep extension of c

b. extracting the CID's for a specific document d in U.

The prior art has never specified storage structures nor the implementation of operations, that are both presented in this context. Abstract storage structures are defined with the following notation. Given domains A1, ..., AN and B1, ..., BM:

- the relation R:[A1, ..., AN] → [B1, ..., BM] means that a N-uple of values drawn from domains A1, ..., AN uniquely identifies an M-uple of values drawn from domains B1, ..., BM. If [A1, ..., AN] → [B1, ..., BM] holds, then any [A1, ..., AN] → [Bi] holds, where Bi is drawn from any domain in the set {B1, ..., BM}
- the relation R:[A1, ..., AN] → { B1, ..., BM} means that a N-uple of values drawn from domains A1, ..., AN uniquely identifies a set of M-uples of values drawn from domains B1, ..., BM. If [A1,

…, AN] → {B1, …, BM} holds, then any [A1, …, AN] → {Bi} holds, where Bi is drawn from any domain in the set {B1, …, BM}.

When brackets are omitted in the right part, square brackets are assumed.

Abstract relations can be trivially mapped (for the purpose of illustration, and with no intent to restrict their representation) to relations in a relational schema, in the following way:

R: R:[A1, …, AN] → [B1, …, BM] maps into R(A1, …, AN, B1, …, BM)

R: R:[A1, …, AN] → {B1, …, BM} maps into a set of 4^{th} NF relations Ri(A1, …, AN, Bi)

where underlined domains are key attributes of R. Abstract SQL queries on these relations will be used to express operations. When expedient, the notation A.B applied to an abstract relation [A] → [B] or [A] → {B} will be used to denote the value or the set of values of B corresponding to a given value of A. Domain CID holds the abstract labels of concepts, i.e. stands for the set of values {CID(c), for all c in the taxonomy}. Domain DID holds the abstract labels of documents, i.e. denotes the set of values {DID(d), for all d in U}.

Abstract structures to store the intension will now be described.

The intension is the taxonomy itself; it can be seen as a conceptual schema for a set of corpora. The intension is stored as:

AIS1. One or more "dictionary" relations in the form

Di: [CID] → [textualLabel]

storing the user-visible definition of each concept; the domain "textualLabel" holds natural language descriptions of concepts. Each dictionary can be in a different "language", thereby allowing multilingual corpora and/or different descriptions of concepts.

AIS2. A language directory, identifying the appropriate dictionary relation for a specific "language" (required only if more than one "language" for concept description is used) in the form:

LD:[LANGUAGE_ID] → D

where LANGUAGE_ID holds the abstract identification of languages and D holds the existing dictionaries.

An alternate representation of AIS1, AIS2 is by a single relation

AIS1': [CID, LANGUAGE_ID] → textualLabel.

AIS3. A father to son relation in the form

FS:[CID] → {SON_CID}

or

FS':[CID, SEQ] → [SON_CID]

storing, for each concept c, its sons in the taxonomy. The domain SON_CID is the same as CID. The domain of SEQ is the set of natural numbers.

The second form, which is generally used, allows to supply a meaningful display order among the sons of a concept c.

AIS4. A son to father relation, in the form

SF: [CID] → {FATHER_CID}

storing, for each concept c, its fathers in the taxonomy. The domain FATHER_CID is the same as CID. If the taxonomy is not a lattice (i.e. any concept c can have no more than one father), this relation becomes:

SF: [CID] → [FATHER_CID].

In this latter case, information on the father of a specific concept c may alternatively be stored in the dictionaries as:

Di:[CID] → FATHER_CID, textualLabel

although this results in redundancy if more than one dictionary is maintained.

Abstract storage structures for the extension will now be described.

The extension represents the classification of documents. As such, it depends on the specific corpus. The extension is abstractly represented by the following three relations:

AES1. Deep extension, in the form

DE:[CID] → {DID}

storing, for each concept c, all the documents in its deep extension (that is, all the documents classified under c or under any descendant c' of c).

AES2. Shallow extension, in the form

SE: [CID] → {DID} equivalent to [CID, DID]

storing, for each concept c, all the documents in its shallow extension (that is, all the documents directly classified under c). The shallow extension and the deep extension are the same for terminal concepts, so that for such terminal concepts only one of DE and SE needs to be kept (typically, DE will be kept).

AES3. Classification, in the form

CL:[DID] → {CID}

storing, for each document, the most specific concepts under which it is classified. All the

ancestors of these concepts can be easily recovered through the son-to-father (SF) relation in the intension. This structure is required only if the display of the classification for stored documents is supported at the user level. This storage structure is optional, since the set K of concepts under which a specific DID is stored can be synthesized by operation AE05 applied to each concept c in T on the singleton set {DID}. A concept c is then in K if and only if operation AE05 returns TRUE.

AES4. Document directory

Not specified, since it depends on the host system. It maps a document id into information required to retrieve the specific document (for example, the file name).

The abstract implementation of operations on the intension will now be described.

AIO1. Given a concept c identified by K=CID(c), find its label in a specific language L.

1. Access the appropriate language directory

```
SELECT D
FROM LD
WHERE LANGUAGE_ID=L
```

2. Use K as a key to access the textual label

SELECT textualLabel

FROM D

WHERE CID=K

AIO2. Given K=CID(c) find all its sons.

Access the father-to-son relation FS, using K as a partial key

SELECT SON_CID

FROM FS

WHERE CID=K

Or

Access the father-to-son relation FS', using K as a partial key

SELECT SEQ, SON_CID

FROM FS'

WHERE CID=K

ORDER BY SEQ, SON_CID

AIO3. Given a K=CID(c), find all its fathers.

Access the son-to-father relation SF, using K as a partial key

SELECT FATHER_CID

FROM SF

WHERE CID=K

AIO4. Insert, delete, change operations.

Insert operations are performed by inserting the new concept C:

- in the dictionaries (AIS1)

- in the father to son relation (AIS3)

- in the son to father relation (AIS4)

If C is a son of another concept C', it may be useful to allow the user to reclassify under C some of the documents presently classified in the shallow extension of C'.

In the case in which each concept has a single father in the taxonomy, the deletion of a concept C is performed by deleting from the intension (AIS1, AIS3, AIS4) all concepts $c \in C^{down}(C)$. In addition (in order to avoid losing documents), the documents in the deep extension of C should be added to the shallow extension of C', where C' is the father of C in the taxonomy, unless C' is the root of the taxonomy. The shallow (AES2) and deep (AES1) extensions for all concepts $c \in C^{down}(C)$ must be removed. The concepts in $C^{down}(C)$ must be removed

from the classification (AES3) of all the documents in the deep extension of C.

Alternatively, and in the general case in which concepts can have multiple fathers, we proceed as follows.

Define LinkDelete(f, s) as:

1. remove from AIS3 the instance where CID=CID(f) and SON_CID=CID(s)
2. remove from AIS4 the instance where CID=CID(s) and FATHER_CID=CID(f)

Define BasicDelete(c) as:

1. for each f in {f: f is a father of c} call LinkDelete(f, c)
2. remove the deep (AES1) and shallow (AES2) extension for c, its classification (AES3), and any dictionary entries associated with c.

Define RecursiveDelete(f, s) as:

1. if f is the only father of s then
   1.1. for each s' in {s': s' is a son of s} call RecursiveDelete(s, s')
   1.2. call BasicDelete(s)
2. else call LinkDelete(f, s)

Define RecomputeDeepExtension(c) as:

1. for each s in {s: s is a son of c}

1.1. set the deep extension of c: DeepExtension(c) = DeepExtension(c) union RecomputeDeepExtension(s)

2. return(DeepExtension(c))

Define UpdateDeepExtension(c) as:

1. for each f in { f: f is a father of c }

1.1. DeepExtension(f)=DeepExtension(c) union ShallowExtension(f)

1.2. UpdateDeepExtension(f)

Deletion of c is then implemented as:

1. Compute the set F(C), which represents all the fathers of the concept to be deleted (accessible through relation AIS4). All and only the concepts in F(C) and their ancestors will have their deep extension affected by the deletion of C.
2. For each s in {s: s is a son of C}, call RecursiveDelete(C, s)
3. Call BasicDelete(C).
4. Recompute the deep extension of all the fathers of C: for each f in F(C) call RecomputeDeepExtension(f)
5. Update the deep extension of all the ancestors of the set F(C):

5.1. For each f in F(C) call

UpdateDeepExtension(f)

Changes in the taxonomy may be of three types:

1. changing the labeling of a concept C: this only requires the modification of the textualLabel in AIS1
2. changing the place of a concept C in the taxonomy
3. adding an additional father C' to C in the taxonomy

In case 2, let C' be the current father of C and C" the new father of C. First, C must be deleted from the taxonomy, and reinserted with C" as a father. The deep extension of C must be deleted from the deep extension of all concepts $c \in C^{up}(C')$ (by set subtraction, or by applying the above algorithm for deletion with steps 2 and 3 replaced by C reparenting). The deep extension of C must be added to the deep extension of all concepts $c \in C^{up}(C")$ (by set union). No changes in shallow extensions are required.

In case 3, the deep extension of C must be added to the deep extension of all concepts $c \in C^{up}(C')$ (by set union).

The abstract implementation of operations on the extension will now be described.

AEO1. Given a concept c such that CID(c) = K, find its deep extension.

Access the deep-extension relation DE, using K as a partial key

```
SELECT DID
FROM DE
WHERE CID=K
```

AEO2.Given a concept c such that CID(c) = K, find its shallow extension.

Access the shallow extension relation SE, using K as a partial key

```
SELECT DID
FROM SE
WHERE CID=K
```

AEO3. Test the membership of a set of DIDs {DID} in the deep extension of a concept CID.

1. Retrieve the deep extension of CID
2. For each d in {DID}, test whether d belongs to the deep-extension; if it does, return TRUE; if no d in {DID} does, return FALSE

AEO4. Given a set of DIDs {DID}, count the number of documents in {DID} which are also in the deep extension of CID.

1. Retrieve the deep extension of CID
2. Initialize CNT to 0
3. For each d in {DID}, test whether d belongs to the deep-extension; if it does, CNT=CNT+1
4. Return CNT

AEO5. Test the membership of a set of DIDs {DID} in the shallow extension of a concept CID.

As in AEO3, by substituting the deep extension with the shallow extension.

AEO6. Given a set of DIDs {DID}, produce the projection under a concept CID.

1. Retrieve the set {SON} of all the sons of CID
2. Initialize set R to empty
3. For each concept s in SON, use operation AEO3, or operation AEO4 if counters are desired, to test the membership of {DID} in s. If the operation returns TRUE (>0 if AEO4 is used) add s to list R
4. Return R

AEO7. Given a set of DIDs {DID}, produce the reduced taxonomy for {DID}.

As a clarification, the set of DIDs for which the reduced taxonomy has to be produced can be generated by operations on the taxonomy and also by any other means, including, without loss of generality, database queries and information retrieval queries. Also, the current combination of concepts can be used as a pre-filter for other retrieval methods.

For performance reason, the reduced taxonomy is usually produced on demand: the request only displays the highest levels in the tree. The set {DID} is kept in memory, so that when the explosion of a specific concept in the reduced taxonomy is requested, appropriate filtering is performed.

1. Produce the projection of {DID} for the root

On the subsequent explosion of concept c:

Produce the projection of {DID} for c

The reduced tree can also be totally computed in a single step. Let RT be the set of concepts in the reduced tree. RT can be computed by testing, for each concept c in T, the membership of { DID } in c through operation AEO3 or AEO4 (if counters are required). Concept c is in RT if and only if operation AEO3 returns TRUE or operation AEO4 returns a counter larger than 0.

The computation can be speeded up in the following way:

1. Initialize a table S of size |T|, where S[i] holds information on the current status of concept i, initialized at "pending".
2. Starting from the uppermost levels, and continuing down in the tree, process concept i.
   2.1. If S[i] is "empty", i does not belong to RT, and processing can continue with the next concept.
   2.2. If S[i] is not "empty", apply operation AEO3 or AEO4 to i.
      2.2.1. If the operation returns TRUE (AEO3) or a counter larger than 0 (AEO4), i belongs to RT.
      2.2.2. Otherwise, neither i nor any of its descendants belong to RT: set to "empty" all S[j] in S, such that j is a descendant of i in the taxonomy. Descendants can be efficiently obtained by keeping a precomputed table D, holding for each concept in the taxonomy a list of all the concepts descending from it in the taxonomy (such a table must be recomputed every time the taxonomy changes).

AEO8. Boolean combination of concepts.

Boolean combinations of concepts are performed through the corresponding set operations on the deep extension of concepts. Let c and c' be two concepts, and DE(c) and DE(c') their deep extension (represented by AES1):

c AND c' corresponds to $DE(C) \cap DE(c')$

c OR c' corresponds to $DE(c) \cup DE(c')$

c MINUS c' corresponds to DE(c)-DE(c')

NOT c corresponds to U-DE(c), where U is the universe

AEO9. Insertion of a new document.

The insertion of a new document d (represented by DID(d)) classified under a set of concepts {C} requires the following steps:

for each $c \in \{C\}$

1. insert DID(d) in the shallow extension of c (AES2), if c is not a terminal concept and the shallow extension must be stored
2. insert DID(d) in the deep extension (AES1) of $C^{up}(c)$.
3. insert an item [DID(d)] → {C} in the classification structure AES3

AEO10. Deletion of an existing document.

The deletion of a document d (represented by DID(d)) requires the following steps:

1. retrieve the set of concepts {C} under which d is shallowly classified, by accessing AES3 with DID(d) as the key (operation AEO2)
2. for each $c \in \{C\}$
   a. delete DID(d) from the shallow extension of c
   b. for all $c' \in C^{up}(c)$: delete DID(d) from the deep extension of c'
3. delete the entry corresponding to DID(d) from AES3.

If AES3 is not stored, deletion is performed in the following way. For each concept c in T, if d belongs to the shallow extension of c:

1. delete DID(d) from the shallow extension of c
2. for all $c' \in C^{up}(c)$: delete DID(d) from the deep extension of c'

AEO11. Document reclassification.

Changes in the classification of a document d (represented by DID(d)) are implemented in the following way. Let d be initially classified under a concept c (possibly null) and let the new concept under which d must be classified be c' (possibly null). If both c and c' are non-null, the operation

means that d was previously classified under c and must now be classified under c'; if c is null, the operation means that d is additionally classified under c'; if c' is null, the operation means that the original classification under c must be removed. At least one of c and c' must be non-null.

If c is not null:

1. eliminate DID(d) from the shallow extension (AES2) of c
2. eliminate DID(d) from the deep extension (AES1) of all c" $\in C^{up}$ (c)
3. eliminate c from the classification of d (AES3)

If c' is not null:

1. insert DID(d) in the shallow extension (AES2) of c' (if the shallow extension of c exists)
2. insert DID(d) in the deep extension (AES1) of all c" $\in C^{up}$ (c')
3. insert c' in the classification of d (AES3)

AEO12. Find the concepts under which a document d is immediately classified.

Retrieve {C} from AES3, using DID(d) as a key.

Physical storage structures, architecture and implementation of operations will now be described.

As regards the intension, storage structures usually contribute with a negligible overhead to the overall storage cost, since a few thousand of concepts are usually adequate even for semantically rich corpora. Storage for these structures may be provided by any database management system or any keyed access method. The second form of AIS3 (FS') requires an ordered access, since SEQ is used to order the sons of a specific concept. Because of the low overhead, all the intensional storage structures (with the possible exception of AIS1, the dictionaries) may be usually kept in central memory.

As regards the extension, the most critical component is AES1 (the deep extension), for several reasons. First, deep-extension semantics are the natural semantics for boolean combinations of concepts (see AEO8). Second, the production of reduced taxonomies requires a possibly large number of projections (which are performed on the deep extension), whose performance is critical for visual operations.

It is critical that the deep extension of concept c is explicitly stored, and not computed as

the union of the shallow extensions of all the descendants of c.

Although any dbms or keyed access method can be used to provide storage for the deep extension, the set of documents in the deep extension can be more efficiently represented than by straightforwardly mapping the abstract relation.

The use of fixed size bit vectors in the present context will now be described. Information data bases with a small-to-moderate number of documents can effectively represent the deep extension of a concept c by bit vectors, each of size equal to |U'|, the maximum number of documents in the universe. In the bit vector, bit i is set if and only if the document d with DID(d)=i is in the deep extension of c.

Set operations on the deep extension only involve logical operations on bit vectors (AND, OR, NOT, etc.). These operations take one or more bit vectors and produce a result bit vector of the same size.

Let document id's be numbered 0 to |U'|-1, and n be the number of bits in the word of the host CPU. For performance reasons, it is better to set the fixed size of bit vectors at $\lceil |U'|/n \rceil$, in order to

be able to perform bit operations at the word level. Unused bit positions are left unset.

Counting the number of documents in the result of any operation can be efficiently performed by table lookup, in the following way.

Let the unit of access UA (not necessarily the CPU word) be n bits. Build once a vector V of 2^n elements, stored in memory, which stores in V[i], the number of bits set in the binary number 2^i, $0 <= i <= 2^n - 1$.

Counting:

Initialize counter C at 0;

Access the bit vector in chunks of n bits at a time:

for each chunk

store the chunk in i

set C = C + V[i]

For access at the octet level (n=8), the translation table requires no more than 256 octets. For access at the double octet level (n=16), no more than 64K octets. Larger units of access are not recommended.

Insertion, deletion and reclassification are also efficiently performed, by simply locating the

appropriate deep and/or shallow extension and setting/resetting the appropriate bit.

This same representation can be trivially used for storing structures AS2 and AS3. In AS3 the size of the bit vector is equal to the cardinality of the set of concepts in the taxonomy.

As regards compressed bit vectors, by construction, the deep extension is very sparse at terminal level, and very dense at the top levels in the taxonomy. The use of any type of bit vector compression (such as, without prejudice to generality, Run Length Encoding (see Capon J., "A probabilistic model for run-length coding of pictures", IEEE Trans. on Inf. Theory, 1959) and/or variable-length bit vectors) is therefore beneficial in reducing the overall storage overhead, although it introduces a compression/decompression overhead.

If a controlled error-rate in operations is acceptable, Bloom filters (see Bloom, B. H., Space/time tradeoffs in hash coding with allowable errors, Comm. of the ACM, 1970) can be used to represent the deep extension in a compact form, suitable for larger information bases. With Bloom

filters, counting and set negation are usually not supported.

For large to very large information bases, a bit vector representation (albeit compressed) may produce an excessive storage overhead. The deep and shallow extensions as well as structure AES3 may be stored as inverted lists (see Wiederhold, G., Files structures, McGraw-Hill, 1987). Because of performance in the computation of set operations, such lists (and the result of set operations) are kept ordered by document id's. For the above-cited statements, it is generally advantageous to use any form of inverted list compression.

As regards the general architectural strategies, the implementation of dynamic taxonomies should try to keep all the relevant data structures in main memory, shared by the processes accessing them.

As noted before, the intension overhead is generally negligible so that intensional structures (with the possible exception of dictionaries) may be usually kept in memory without problems.

Extension overhead for extensional structures is considerably larger. If the storage overhead prevents the complete storage of deep-extension

structures, buffering strategies should be used, such as LRU or the ones described in documents Johnson, T., Shasha D.: 2Q: A Low Overhead High Performance Buffer Management Replacement Algorithm, Int. Conf. on Very Large Databases, 1994; and O'Neill, et al.: The LRU-K Page Replacement Algorithm For Database Disk Buffering, SIGMOD Conf. 1993. Shallow extensions and classification structures are less critical and may be kept on disk (again with the buffering strategies described in the two above-mentioned documents).

As indicated in operation AEO3, the membership test without counting can return TRUE when the first DID common to both lists is found, thereby speeding up the computation.

The use and implementation of virtual concepts will now be described.

Some data domains (such as price, dates, quantities, etc.) correspond usually to a concept (e.g. PRICE) which can be expanded into a large number of terminal concepts, each representing a specific value (e.g. 100$). Such a representation causes a high number of son concepts, and increases the complexity of the taxonomy. Alternatively,

values can be grouped by defining meaningful intervals of values and representing only the intervals as specific concepts. This representation loses the actual data, and presents the user with a fixed classification. Grouping may also be combined with exhaustive representation, but inherits most of the problems of both schemes.

The invention of "virtual concepts" provides a third, more flexible alternative. We define a "Simple virtual concept" as a concept for which neither the actual sons (actual values of the domain to be represented) nor the actual extension are stored, but are computed (usually from additional, possibly external data).

A virtual concept is completely described by 4 abstract operations:

V1: Given a virtual concept v, retrieve all its sons.

V2: Given a virtual concept v, retrieve its deep extension.

V3: Given the son s of a virtual concept v, retrieve its deep extension.

V4: Given a document d, find all the terminal concepts (descendants of v) under which it is stored.

One way of implementing these abstract operations is by keeping, for each virtual concept v, two abstract relations:

S_v: [value] → {DID}

which stores the set of documents with a given value in the domain of values of the virtual concept.

C_v: [DID] → {value}

which stores the set of values for a specific document; if each document has a single value C_v: [DID] → [value]. A single C_v relation may store multiple domains and be shared by many virtual concepts: in this case C_v: [DID] → {valueA, …, valueN}, where valueI denotes the set of values for domain I. It is important to note that neither S_v nor C_v need to be explicitly stored, but they can be also synthesized by queries on external data.

These two abstract relations can be represented by a single relation in a relational schema (without loss of generality and simply to provide a clear description of operations)

C_v(<u>DID, value</u>)

with underscored attributes representing the primary keys. S_v actually stores the inversion of C_v

and will usually be represented by a secondary index on C_v, rather than by a base relation.

With this representation, the abstract operations defined before can be easily implemented by SQL queries:

V1: Given a virtual concept v, retrieve all its sons:

SELECT DISTINCT value

FROM C_v

V2: Given a virtual concept v, retrieve its deep extension:

SELECT DISTINCT DID

FROM C_v

V3: Given the son s of a virtual concept v, retrieve its extension (s is a terminal concept, so that its deep and shallow extension are the same)

SELECT DISTINCT DID

FROM C_v

WHERE value=s

Counting is trivially added.

V4: Given a document d, find all the terminal concepts (descendants of v) under which it is stored

RETRIEVE DISTINCT value

FROM C_v

WHERE DID=d

In general, a virtual concept v can be organized into a sub-taxonomy, i.e. each non-terminal son of v represents a set of actual domain values. Each son may be further specialized, and so on. For instance SALARY can be organized into the following taxonomy:

SALARY

Low (e.g. <1000)

Medium (e.g. >=1000 and <10000)

High (e.g. >10000)

In this case, the non-terminal descendants of v can be stored as derived virtual concepts, i.e. virtual concepts referencing the same abstract relations defined for v, but providing additional restrictions. In the example, "Low" can be characterized by the additional restriction value<1000, so that operation V3 for Low becomes:

SELECT DISTINCT DID

FROM C_v

WHERE value<1000

Virtual and derived virtual concepts are peculiar in that their terminal descendants and their extensions are not directly stored but computed. In order to represent them in our

framework, the following abstract relations are added to the intension:

AIS5: [CID] → [conceptType]

where conceptType designated real, simple virtual and derived virtual concepts.

AIS6: [CID]→[S_{CID}]

for simple virtual concepts, stores the abstract relation Sv (which can synthesized be a query) for the virtual concept CID

AIS7: [CID]→[C_{CID}]

for simple virtual concepts, stores the abstract relation Cv (which can synthesized be a query) for the virtual concept CID

AIS8: [CID]→[CID', restriction]

for derived virtual concepts only, identifies the virtual concept to refer to and the additional restriction.

The use and implementation of time-varying concepts will now be described.

Time-varying concepts, such as age, can be represented by a simple variant of virtual concepts. A time instant t is represented as an abstract "timestamp". The timestamp contains the number of clock ticks starting from a fixed time origin; the clock resolution depends on the

application. All timestamps use the same time coordinates. The difference between two timestamps t and t′ defines the time interval amplitude between the two times. Let the values of the virtual concept v be the set of timestamps of all documents in the extension of v, and let T be the timestamp of the current time, and the sons of v be represented as time intervals with respect to the current timestamp T:

Given a virtual concept v, retrieve all its sons:

SELECT DISTINCT T-value

FROM C_v

Given a virtual concept v, retrieve its deep extension:

SELECT DISTINCT DID

FROM C_v

Given the son s of a virtual concept v, retrieve its extension

SELECT DISTINCT DID

FROM C_v

WHERE value=T-s

Alternatively, and more efficiently, the values of the time-varying concept can be split into N intervals (from more recent to older), which

are stored as real concepts. In addition, for each interval I, we keep:

a. the list L(I) of DIDs in the interval ordered by decreasing timestamps (i.e. newer to older)

b. in central memory, an interval representative IR(I): the last DID in the interval together with its timestamp

c. a classification criterion (e.g. T-value less than 1 week and no smaller than 1 day)

Since the classification of documents varies with time, we need to re-compute the classification of documents every time tick (arbitrary time interval selected by the system administrator, typically a multiple of clock resolution), according to the following algorithm:

At each time tick:

For each interval I

while IR(I) needs reclassification (i.e. it fails the classification criterion for I) do

{

Reclassify(IR(I));

set as IR(I) the last DID in the ordered list a)

}

where Reclassify(IR(I)) is

```
Delete IR(I).DID from I
For(i=i+1 to N)
{
    if IR(I).timestamp meets the classification
criterion for interval i
    {
        insert IR(I) in interval i
        break;
    }
}
```

Binding a dynamic taxonomy to a database system will now be described.

The present invention allows to use a dynamic taxonomy to browse and retrieve data stored in a conventional dbms (relational, object-relational, object-oriented, etc.). The invention covers data stored as a single relation (or object) or, more generally, represented by a single view on the database (see Elmasri, Navathe, Fundamentals of database systems, The Benjamin/Cummings Publ. Co., 1994).

In this case documents correspond to tuples (or rows, records, objects) in the view V. In order to identify a document we can either use the primary key of the view as a document identifier

(DID) or keep two abstract relations mapping system-generated DID's to and from the primary key PK of the view:

DK: [DID] → [PK]

IDK: [PK] → [DID]

where PK represents the primary key of the relation. DK is used to access a tuple of V, given a document id DID, and IDK is used to retrieve the document id corresponding to a specific value in the primary key of V. This latter representation is beneficial when primary keys PK's are large (e.g. when they are defined on alphanumeric attributes).

Given a view V we can construct a taxonomy T for V in the following way. For each attribute A in V, we place a corresponding concept C(A) (either a real or a virtual one) as an immediate son of the root. Virtual concepts use V itself for the synthesis of sons and extensions (as previously seen). Real concepts can be further specialized as required by the semantics of A.

Given a tuple t in V, for each attribute A in V, let t.A denote the value of attribute A in t. For each real concept C in T (either C(A) or a descendant of C(A)), the designer must provide a boolean clause B(C, t) such that t (represented by

DID(t)) is to be classified under C if and only if B(C, t)=TRUE.

The boolean clause B(C, t) may reference any attribute of t, and consequently, new virtual concepts (called "extended concepts") may be defined on combinations of attributes by operations on the database (including but not restricted to sums, averages, etc. of database values).

A special case occurs when the boolean clause B(C, t) is true when $t.A \in S_C$, where S_C is a set of values of attribute A and $S_C \cap S_{C'} = \emptyset$, for $\forall C \neq C'$. In this case, it is more efficient to keep a table T:[v] →[c], listing for each value v in domain(A), the corresponding concept c. If $S_C \cap S_{C'} \neq \emptyset$, for $\exists C \neq C'$, multiple concepts can be associated with the same value, so that T:[v] → {c}.

In addition to this mapping among attributes and concepts, the designer may define new concepts either as taxonomic generalizations of attributes or extended concepts.

- New taxonomic generalizations. For virtual concepts, this feature was discussed previously. If the sons of a new taxonomic generalization G are real concepts {S}, no boolean clause is

usually required for G, because classification under G is automatically performed by operation AE09.

- Extended concepts. New concepts may be derived either as real or virtual concepts by operations on the database (including but not restricted to sums, averages, etc. of database values).

Binding is then performed in the following way. Virtual concepts do not require any special processing, since they are realized by operations on the database. Real concepts require a classification for any new tuple, a deletion if t is deleted or a reclassification if t is changed. In order to classify t, the system locates the set C of concepts for which B(c, t), $c \in C$ is satisfied and classifies t under $\forall c \in C$ (and, consequently under all of c's ancestors). Deletion and reclassification are performed as previously stated.

Example:

Given the relation R:(TOWNID, NAME, COUNTRY, POPULATION), we can identify the documents in the database by the values of TOWNID. We need to decide which attributes will be represented in T and how

they will be represented. Let COUNTRY be represented by a real concept, and NAME be represented by a virtual concept. In addition we define the real concept CONTINENT as the continent the COUNTRY is in. CONTINENT can be represented in two ways: as a taxonomic generalization concept or as an extended concept.

If we represent CONTINENT as an extended concept, the taxonomy T will be:

NAME

Sv:Select TOWNID FROM R WHERE NAME = x

Cv:Select DISTINCT NAME FROM R

CONTINENT

EUROPE t.COUNTRY="Italy" or t.COUNTRY="France" or …

AMERICA t.COUNTRY="USA" or …

ASIA t.COUNTRY=…

COUNTRY

Italy t.COUNTRY="Italy"

France t.COUNTRY="France"

Usa t.COUNTRY="USA"

…

If we represent CONTINENT as a taxonomic generalization of COUNTRY, the taxonomy T' will be:

NAME

Sv:Select TOWNID FROM R WHERE NAME = x

Cv:Select DISTINCT NAME FROM R

CONTINENT

EUROPE

Italy t.COUNTRY="Italy"

France t.COUNTRY="France"

AMERICA

Usa ...

...

ASIA

...

COUNTRY

Italy t.COUNTRY="Italy"

France t.COUNTRY="France"

Usa t.COUNTRY="USA"

...

In both cases, NAME is represented in the same way. For NAME, we have two abstract relations

Sv:[COUNTRY] →{TOWNID}

Cv:[TOWNID] → [COUNTRY]

POPULATION is represented in an analogous way.

Finally, the use of dynamic taxonomies to represent user profiles of interest and implementation of a user alert for new interesting documents based on dynamic taxonomy profiles, will be described.

The invention consists in using set-theoretic expressions on concepts (plus optional, additional expressions, such as information retrieval queries) to describe user interest in specific topics. Such expressions may be directly entered by the user or transparently and automatically captured by the system, by monitoring user query/browsing. The specification of user profiles is especially important in electronic commerce and information brokering and in monitoring dynamic data sources in order to advise users of new or changed relevant information. The information base is assumed to be classified through dynamic taxonomies.

The scenario is as follows. Several users express their interests through possible multiple conceptual expressions, called "interest specifications". A monitoring system accepts these requests (with an abstract user "address" to send alerts to). The monitoring system also monitors an information base for changes (insertion, deletion, change). The information base is described by the same taxonomy used by users to express their interests.

When a change occurs in the information base (the type of change to be alerted for may be

specified by users), the system must find the users to alert on the basis of their interests.

A brute force approach will check all user interest specifications exhaustively, and compute whether each changed document d satisfies any given specification S. We can test whether a document d satisfies a specification S by applying the query specified in S to the singleton set {d} and test if d is retrieved. However, this strategy requires to perform, for each information base change, as many queries as there are user specifications and may be quite expensive in practice. For this reason, we define alternate strategies which reduce the number of evaluations required.

We are primarily interested into the efficient solution of dynamic taxonomy specifications. Additional expressions, such as information retrieval queries, will usually be composed by AND with taxonomic expressions, and can therefore be solved, if required, after the corresponding taxonomic expression is satisfied.

We will start from the simplest case, in which:

a) the specification is expressed as a conjunction of terminal concepts;

b) documents are classified under terminal concepts only.

As regards conjunctive specifications and document classification under terminal concepts only, we use two abstract storage structures:

1. a directory of specifications, in the form:

SD: [SID] → [N, SPEC]

where SID is an abstract identifier which uniquely identifies the specification, SPEC is the specification itself (optional), N is the number of concepts referenced in the specification. Optionally, other fields (such as the user "address") will be stored in this structure.

2. a specification "inversion", in the form:

SI: [CID] → {SID}

listing for each concept c (represented by its concept identifier) all the specifications (represented by their specification id) using that concept.

When a specification is created, its abstract identifier is created, its directory entry is created in SD and the set of concepts referenced in the specification are stored in the inversion SI.

When a document d is inserted, deleted or changed, let C be the set of concepts (terminal

concepts by assumption) under which d is classified. The set of specifications that apply to d are then found in the following way.

Let K be the set of concepts used to classify document d. For each concept k in K, let SID(k) be the list of specifications for k (accessible through relation SI) ordered by increasing specification id's. We define MergeCount(K) as the set composed of pairs (SID, N) such that SID is in MergeCount(K) if SID belongs to a SID(k), k in K. If the pair (SID, N) is in MergeCount(K), N counts the number of SID(k) referencing SID. MergeCount(K) can be produced at a linear cost, by merging the SID(k) lists.

Let S be a set initially empty, which represents the set of specifications satisfied by d.

```
For  each pair (SID, N)
     retrieve SID.N from SD;
     if SID.N=N: S=S union SID
```

As regards specifications using unrestricted set operations, let S (represented by SID(S)) be a specification. Transform S into a disjunctive normal form (i.e. as a disjunction of conjunctions). Let each conjunctive clause in S be

called a component of S. We denote by SIDi(S) the i-th component of S.

Store the directory of specifications as two abstract relations:

SD (as before, with N omitted)

SCD: [COMPONENT] → [SDI, N], where COMPONENT stores components of specifications, COMPONENT.SDI represents the specification id of the specification S of which COMPONENT is a component, and COMPONENT.N is the number of concepts referenced in the component.

The specification inversion is stored as:

SI: [CID] → {COMPONENT}, where CID is a concept identifier and CID.COMPONENT is the set of components referencing the concept identified by CID.

Let K be the set of concepts used to classify document d, for each concept k in K, let COMPONENT(k) be the list of components for k (accessible through relation SI) ordered by increasing component id's. Define ComponentMergeCount(K) as the set composed of pairs (COMPONENT, N) such that COMPONENT is in ComponentMergeCount(K) if COMPONENT belongs to a COMPONENT(k), k in K. If the pair (COMPONENT, N) is

in ComponentMergeCount(K), N counts the number of COMPONENT(k) referencing COMPONENT. ComponentMergeCount(K) can be produced at a linear cost, by merging the COMPONENT(k) lists.

Let S be a set initially empty.

For each pair (COMPONENT, N),

retrieve COMPONENT.N through relation SCD;

if COMPONENT.N=N: S=S union COMPONENT.SID (COMPONENT.SID is accessed through relation SCD).

S represents the set of specifications satisfied by d.

As regards specifications and document classification under non-terminal concepts to which they refer, the specification inversion SI needs to be modified in the following way.

If a specification or component Z references concept C, represented by CID(C) then:

C is a terminal concept:

CID(C).SID= CID(C).SID union Z, if Z is a specification

CID(C).COMPONENT= CID(C).COMPONENT union Z, if Z is a component

C is a non-terminal concept:

for each k in $C^{down}(C)$

CID(k).SID= CID(k).SID union Z, if Z is a specification

CID(k).COMPONENT= CID(k).COMPONENT union Z, if Z is a component

The set S of satisfied specifications is computed as per the previous cases.

The above-disclosed techniques allow computing the specifications satisfied by a document d. In case it is desired to determine the specifications satisfied by a set of documents D (whose cardinality is greater than 1), the above-disclosed techniques can be applied in two ways. In the first way, the techniques are applied without modifications to every document d in D, then removing possible duplicate specifications. In the second way, K is defined as the set of concepts used to classify D, the adequate technique is chosen among the described ones and the set S of "candidate" specifications is determined. Every specification s in S is then checked, performing it on D.

CLAIMS

1. Process for retrieving information on large heterogeneous data bases, characterized in information retrieval through visual queries/searches supported by dynamic taxonomies, and further characterized in that said process comprises the steps of:

- (F1) initially showing a complete taxonomy for said retrieval;
- (F2) refining said retrieval through a selection of subsets of interest, said refining step being performed by selecting taxonomy concepts and combining them through boolean operations;
- (F3) showing a reduced taxonomy for said selected set; and
- (F4) further refining said retrieval through an iterative execution of said refining and showing steps.

2. Process according to Claim 1, characterized in that it comprises the following aspects of dynamic taxonomies:

a) additional operations;

b) abstract storage structures and operations for the intension and the extension;

c) physical storage structures, architecture and implementation of operations;

d) definition, use and implementation of virtual concepts;

e) definition, use and implementation of time-varying concepts;

f) binding a dynamic taxonomy to a database system; and

g) using dynamic taxonomies to represent user profiles of interest and implementation of a user alert for new interesting documents based on dynamic taxonomy profiles.

3. Process according to Claim 2, characterized in that it further comprises the following operations:

a) projection under a given CID of a set S of DIDs: extraction of all children c of CID such as there is at least a document in S in the deep extension of c; and

b) extraction of CID's for a specific document d in U.

4. Process according to Claim 2, characterized in that the intension is stored as one or more "dictionary" relations (AIS1) in the form Di: [CID] → [textualLabel], said relations storing the user-visible definition of each concept; the domain

"textualLabel" holding natural language descriptions of concepts.

5. Process according to Claim 2, characterized in that the intension comprises a language directory (AIS2), said language directory identifying the appropriate dictionary relation for a specific "language" in the form:

LD:[LANGUAGE_ID] → D

where LANGUAGE_ID holds the abstract identification of languages and D holds the existing dictionaries.

6. Process according to Claim 4 or 5, characterized in that an alternate representation of AIS1, AIS2 is by a single relation:

AIS1': [CID, LANGUAGE_ID] → textualLabel.

7. Process according to Claim 2, characterized in that the intension comprises an abstract father to son relation (AIS3) in the form:

FS:[CID] → {SON_CID}

or

FS':[CID, SEQ] → {SON_CID}

storing, for each concept c, its sons in the taxonomy, said domain SON_CID being the same as CID, said domain of SEQ being the set of natural numbers.

8. Process according to Claim 2, characterized in that the intension further comprises an abstract son to father relation (AIS4), in the form:

SF: [CID] → {FATHER_CID}

storing, for each concept c, its fathers in the taxonomy, said domain FATHER_CID being the same as CID.

9. Process according to Claim 8, characterized in that, if the taxonomy is not a lattice (i.e. any concept c can have no more than one father), said abstract son to father relation (AIS4) becomes:

SF: [CID] → [FATHER_CID],

information on the father of a specific concept c being able to alternatively be stored in the dictionaries as:

Di:[CID] → FATHER_CID, textualLabel.

10. Process according to Claim 2, characterized in that, on the intension, the retrieval operation (AIO1) of the label of a concept c, identified by K=CID(c), in a specific language L, is abstractly implemented, said retrieval operation (AIO1) comprising the steps of:

- accessing the appropriate language directory; and

- using K as a key to access the textual label.

11. Process according to Claim 2, characterized in that, on the intension, the retrieval operation (AIO2) of all the sons of a given K=CID(c) is abstractly implemented, by accessing the father-to-son relation FS, using K as a partial key, or by accessing the father-to-son relation FS', using K as a partial key.

12. Process according to Claim 2, characterized in that, on the intension, the retrieval operation (AIO3) of all fathers of a given K=CID(c) is abstractly implemented, by accessing the son-to-father relation SF, using K as a partial key.

13. Process according to Claim 2, characterized in that, on the intension, the insert, delete, change operations (AIO4) are abstractly implemented.

14. Process according to Claim 13, characterized in that the insert operations (AIO4) are performed by inserting the new concept C in the dictionaries (AIS1), in the father to son relation (AIS3) and in the son to father relation (AIS4).

15. Process according to Claim 13, characterized in that the deletion operations (AIO4) are performed by deleting from the intension (AIS1, AIS3, AIS4)

all concepts $c \in C^{down}(C)$, the documents in the deep extension of C being added to the shallow extension of C', where C' is the father of C in the taxonomy, unless C' is the root of the taxonomy, the shallow (AES2) and deep (AES1) extensions for all concepts $c \in C^{down}(C)$ being removed, the concepts in $C^{down}(C)$ being removed from the classification (AES3) of all the documents in the deep extension of C.

16. Process according to Claim 13, characterized in that the change operations (AIO4) are of three types:

- changing the labeling of a concept C, said change only requiring the modification of the textualLabel in AIS1;
- changing the place of a concept C in the taxonomy; and
- adding an additional father C' to C in the taxonomy.

17. Process according to Claim 2, characterized in that the extension is abstractly represented by a deep extension (AES1), in the form:

DE:[CID] → {DID}

storing, for each concept c, all the documents in its deep extension, that is, all the documents classified under c or under any descendant c' of c.

18. Process according to Claim 2, characterized in that the extension is abstractly represented by a shallow extension (AES2), in the form:

SE: [CID] → {DID} equivalent to [CID, DID]

storing, for each concept c, all the documents in its shallow extension, that is, all the documents directly classified under c.

19. Process according to Claim 2, characterized in that the extension is abstractly represented by a classification (AES3), in the form:

CL:[DID] → {CID}

storing, for each document, the most specific concepts under which it is classified, all the ancestors of these concepts being recovered through the son-to-father (SF) relation in the intension.

20. Process according to Claim 2, characterized in that the extension is abstractly represented by a document directory (AES4) mapping document id's into information required to retrieve the specific document.

21. Process according to Claim 2, characterized in that, on the extension, a retrieval operation

(AEO1) of the deep extension of a concept c, such that CID(c) = K, is implemented, said retrieval operation (AEO1) comprising the step of accessing the deep-extension relation DE, using K as a partial key.

22. Process according to Claim 2, characterized in that, on the extension, a retrieval operation (AEO2) of the shallow extension of a concept c, such that CID(c) = K, is implemented, such retrieval operation (AEO2) comprising the step of accessing the shallow extension relation SE, using K as a partial key.

23. Process according to Claim 2, characterized in that, on the extension, a testing operation (AEO3) is implemented for testing the membership of a set of DIDs {DID} in the deep extension of a concept CID, said testing operation (AEO3) comprising the steps of: retrieving the deep extension of CID; and, for each d in {DID}, testing whether d belongs to the deep extension; if it does, return TRUE; if no d in {DID} does, return FALSE.

24. Process according to Claim 2, characterized in that, on the extension, a counting operation (AEO4) is implemented for counting, given a set of DIDs {DID}, the number of documents in {DID} which are

also in the deep extension of CID, said counting operation (AEO4) comprising the steps of: retrieving the deep extension of CID; initializing CNT to 0; for each d in {DID}, testing whether d belongs to the deep-extension; if it does, CNT=CNT+1; returning CNT.

25. Process according to Claim 2, characterized in that, on the extension, a testing operation (AEO5) is implemented for testing the membership of a set of DIDs {DID} in the shallow extension of a concept CID, said testing operation (AEO5) comprising the steps of: retrieving the shallow extension of CID; and, for each d in {DID}, testing whether d belongs to the shallow extension; if it does, return TRUE; if no d in {DID} does, return FALSE.

26. Process according to Claim 2, characterized in that, on the extension, a producing operation (AEO6) is implemented for producing, given a set of DIDs {DID}, the projection under a concept CID said producing operation (AEO6) comprising the steps of: retrieving the set {SON} of all the sons of CID; for each concept s in SON, using operation AEO3, or operation AEO4 if counters are desired, to test the membership of {DID} in s; if the operation returns

TRUE (>0 if AEO4 is used) adding s to list R; returning R.

27. Process according to Claim 2, characterized in that, on the extension, a producing operation (AEO7) is implemented for producing, given a set of DIDs {DID}, the reduced taxonomy for {DID}, said producing operation (AEO7) comprising the steps of: producing the projection of {DID} for the root; and, on subsequent explosion of concept c, producing the projection of {DID} for c.

28. Process according to Claim 2, characterized in that the boolean operations on concepts are implemented through the corresponding set operations on the deep extension of said concepts (AEO8).

29. Process according to Claim 2, characterized in that, on the extension, an insertion operation (AEO9) of a new document is implemented, said insertion operation (AEO9) comprising the steps of: for each c $\in$ {C}, inserting DID(d) in the shallow extension of c (AES2), if c is not a terminal concept and the shallow extension must be stored; inserting DID(d) in the deep extension (AES1) of $C^{up}(c)$; inserting an item [DID(d)] $\rightarrow$ {C} in the classification structure AES3.

30. Process according to Claim 2, characterized in that, on the extension, a deletion operation (AEO10) of an existing document is implemented, said deletion operation (AEO10) comprising the steps of: retrieving the set of concepts {C} under which d is shallowly classified, by accessing AES3 with DID(d) as the key (operation AEO2); for each c $\in$ {C}, deleting DID(d) from the shallow extension of c; for all c' $\in C^{up}(c)$, deleting DID(d) from the deep extension of c'; deleting the entry corresponding to DID(d) from AES3.

31. Process according to Claim 2, characterized in that, on the extension, a document reclassification operation (AEO11) is implemented, said reclassification operation (AEO11) comprising the steps of: let d be initially classified under a concept c (possibly null) being c' the new concept under which d must be classified (possibly null); if both c and c' are non-null, classifying d under c'; if c is null, additionally classifying d under c'; if c' is null, removing the original classification under c; if c is not null, eliminating DID(d) from the shallow extension (AES2) of c; eliminating DID(d) from the deep

extension (AES1) of all c" $\in C^{up}$ (c); eliminating c from the classification of d (AES3); if c' is not null, inserting DID(d) in the shallow extension (AES2) of c' (if the shallow extension of c exists); inserting DID(d) in the deep extension (AES1) of all c" $\in C^{up}$ (c'); insert c' in the classification of d (AES3).

32. Process according to Claim 2, characterized in that, on the extension, a finding operation (AEO12) is implemented for finding the concepts under which a document d is immediately classified, said finding operation (AEO12) comprising the step of retrieving {C} from AES3, using DID(d) as a key.

33. Process according to Claim 2, characterized in that the deep extension (AES1), the shallow extension (AES2) and the classification (AES3) are represented through bit vectors, said bit vectors being compressed or not.

34. Process according to Claim 33, characterized in that the counting of documents in the result of logic operations on bit vectors is performed through a constant table V whose size is 2^n, whose element V[i] contains the number of bits at 1 in binary number I, and processing the bit vector n

bits at a time, adding to the counter for every group j of n bit, whose binary value is v', the amount V[v'].

35. Process according to Claim 2, characterized by the representation of deep extension (AES2) through Bloom filters.

36. Process according to Claim 2, characterized in that the deep extension (AES1), the shallow extension (AES2) and the classification (AES3) are represented through inverted lists, said inverted lists being compressed or not.

37. Process according to Claim 2, characterized by the use of buffering strategies to manage data.

38. Process according to any one of the previous Claims, characterized in that a simple virtual concept is completely described by four abstract operations:

V1: given a virtual concept v, retrieve all its sons;

V2: given a virtual concept v, retrieve its deep extension;

V3: given the son s of a virtual concept v, retrieve its deep extension; and

V4: given a document d, find all the terminal concepts (descendants of v) under which it is stored.

39. Process according to Claim 38, characterized in that, in order to implement said abstract operations (V1, V2, V3, V4), two abstract relations are kept, for each virtual concept v:

S_v: [value] → {DID}

which stores the set of documents with a given value in the domain of values of the virtual concept; and

C_v: [DID] → {value}

which stores the set of values for a specific document, where S_v represents the inversion of C_v and can therefore not be explicitly stored.

40. Process according to Claim 39, characterized by the implementation of operations V1, V2, V3, V4.

41. Process according to Claim 39, characterized in that a derived virtual concept is described by the same structures as of the simple virtual concepts, with additional restrictions.

42. Process according to Claim 2, characterized in that the intension further comprises the abstract relation (AIS5):

[CID] → [conceptType]

where conceptType designates simple virtual concepts and derived virtual concepts.

43. Process according to Claim 2, characterized in that the intension further comprises the abstract relation (AIS6):

[CID]→[S_{CID}]

which, for simple virtual concepts, stores the abstract relation Sv for the virtual concept CID.

44. Process according to Claim 2, characterized in that the intension further comprises the abstract relation (AIS7):

[CID]→[C_{CID}]

which, for simple virtual concepts, stores the abstract relation Cv for the virtual concept CID.

45. Process according to Claim 2, characterized in that the intension further comprises the abstract relation (AIS8):

[CID]→[CID', restriction]

which, for derived virtual concepts only, identifies the virtual concept to refer to and the additional restriction.

46. Process according to any one of the previous Claims, characterized in that the time-varying concepts, whose value is represented by abstract timestamps, can be represented by virtual concepts,

representing with T the timestamp value of the current time.

47. Process according to Claim 46, characterized in that the sons of a time-varying concept V, represented as a virtual concept, are retrieved through the abstract query:

SELECT DISTINCT T-value

FROM C_v

where T is the current time.

48. Process according to Claim 46, characterized in that the deep extension of a time-varying concept t, represented as a virtual concept, is retrieved through the abstract query:

SELECT DISTINCT DID

FROM C_v.

49. Process according to Claim 46, characterized in that the extension of the son s of a time-varying concept t, represented as a virtual concept, is retrieved through the abstract query:

SELECT DISTINCT DID

FROM C_v

WHERE value=T-s

where T is the current time.

50. Process according to any one of the previous Claims, characterized in that the time-varying

concepts can be split into N intervals (from more recent to older), which are stored as real concepts.

51. Process according to Claim 50, characterized in that, for each interval I, we keep:

a. the list L(I) of DIDs in the interval ordered by decreasing timestamps

b. an interval representative IR(I): the last DID in the interval together with its timestamp

c. a classification criterion for the interval.

52. Process according to Claim 50 or 51, characterized in that the classification of documents is periodically re-computed, according to the following algorithm:

```
For each interval I
while IR(I) needs reclassification do
{
    Reclassify(IR(I));
    set IR(I) = the last DID in the ordered list
a)
}
where Reclassify(IR(I)) is
Delete IR(I).DID from I
For(i=i+1 to N)
{
```

```
    if IR(I) meets the classification criterion
for interval i
    {
        insert IR(I) in interval i
        break;
    }
}.
```

53. Process according to any one of the previous Claims, characterized in that a dynamic taxonomy is used to represent data stored as a single relation (or object) or, more generally, represented by a single view on the database.

54. Process according to Claim 53, characterized in that the documents correspond to tuples (or rows, records, objects) in the view V, and, in order to identify a document, we can either use the primary key of the view as document identifier (DID) or keep two abstract relations mapping system-generated DID's to and from the primary key PK of the view:

DK: [DID] → [PK]

IDK: [PK] → [DID]

where PK represents the primary key of the relation, using DK to access a tuple of V, given a document id DID, and using IDK to retrieve the

document id corresponding to a specific value in the primary key of V.

55. Process according to Claim 54, characterized in that, given a view V, we can construct a taxonomy T for V through the following steps:

- for each attribute A in V, placing a corresponding concept C(A) (either a real or a virtual one) as an immediate son of the root, virtual concepts using V itself for the synthesis of sons and extensions;
- given a tuple t in V, for each attribute A in V, t.A denoting the value of attribute A in t, for each real concept C in T (either C(A) or a descendant of C(A)), providing a boolean clause B(C, t) such that t (represented by DID(t)) is classified under C if B(C, t)=TRUE, said boolean clause B(C, t) referencing any attribute of t.

56. Process according to Claim 55, characterized in that, when the boolean clause B(C, t) is true when $t.A \in S_C$, where S_C is a set of values of attribute A and $S_C \cap S_{C'} = \emptyset$, for $\forall C \neq C'$, a table T:[v] →[c] is kept, listing for each value v in domain(A), the corresponding concept c; if $S_C \cap S_{C'} \neq \emptyset$, for $\exists C \neq C'$,

multiple concepts are associated with the same value, so that T:[v] → {c}.

57. Process according to any one of the previous Claims, characterized in that it further comprises the steps of:

- creating new taxonomic generalizations, said creating step, if the sons of a new taxonomic generalization G are real concepts {S}, not requiring any boolean clause for G, the classification under G being automatically performed by the inserting operation (AEO9) of a new document; and.
- creating extended concepts.

58. Process according to Claim 57, characterized in that the new concepts are derived either as real or virtual concepts by operations on the database, binding among said virtual concepts being realized by operations on the database, binding among said real concepts requiring a classification for any new tuple, a deletion if t is deleted or a reclassification if t is changed, the system, in order to classify t, locating the set C of concepts for which B(c, t), $c \in C$ is satisfied and classifying t under $\forall c \in C$.

59. Process according to any one of the previous Claims, characterized in that it uses said dynamic taxonomies to represent user profiles of interest and implements a user alert for new interesting documents based on dynamic taxonomy profiles.

60. Process according to Claim 59, characterized in that it comprises the steps of:

- acquiring multiple conceptual expressions from a user, said conceptual expressions defining subjects in which the user is interested;
- accepting said conceptual expressions by a monitoring system;
- coupling, by said monitoring system, an abstract user address, to which alerts are to be sent, to said conceptual expressions;
- monitoring, by said monitoring system, an information base for changes (insertion, deletion, change) performed thereto, said information base being described by the same taxonomy used by users to express their interests;
- when a change occurs in the information base, finding, by said monitoring system, the users to be alerted on the basis of their interests.

61. Process according to Claim 60, characterized in that, to realize said monitoring step, dynamic taxonomy concepts are used for which additional expressions, such as information retrieval queries, are composed by AND with taxonomic expressions, and are solved, if required, after the corresponding taxonomic expression is satisfied.

62. Process according to Claim 61, characterized in that it can be checked whether a document d satisfies a user specification S by applying the query specified in S to the set {d} and checking whether d is retrieved.

63. Process according to Claim 62, wherein, if specifications only comprise conjunction operations and document classification is only under terminal concepts, two abstract storage structures are used:

- a directory of specifications, in the form:

SD: [SID] → [N, SPEC]

where SID is an abstract identifier which uniquely identifies the specification, SPEC is the specification itself (optional), N is the number of concepts referenced in the specification;

- a specification "inversion", in the form:

SI:[CID] → {SID}

listing for each concept c (represented by its concept identifier) all the specifications (represented by their specification id) using that concept.

64. Process according to Claim 61, wherein, when a specification is created, its abstract identifier is created, its directory entry is created in SD and the set of concepts referenced in the specification are stored in the inversion SI.

65. Process according to Claim 61, wherein, when a document d is changed, C being the set of concepts under which d is classified, the set of specifications that apply to d are then found in the following way: K being the set of concepts used to classify document d, for each concept k in K, SID(k) is the list of specifications for k (accessible through relation SI) ordered by increasing specification id's; defining MergeCount(K) as the set composed of pairs (SID, N) such that SID is in MergeCount(K) if SID belongs to a SID(k), k in K; if the pair (SID, N) is in MergeCount(K), N counts the number of SID(k) referencing SID; if S is an initially empty set, which represents the set of specifications

satisfied by d, for each pair (SID, N), retrieving SID.N from SD; if SID.N=N: S=S union SID.

66. Process according to Claim 61, wherein, when there are specifications using unrestricted set operations, S (represented by SID(S)) is a specification, and the following steps are provided:

- transforming S in disjunctive normal form (i.e. as a disjunction of conjunctions), each conjunctive clause in S being called a component of S, SIDi(S) denoting the i-th component of S;
- storing the directory of specifications as two abstract relations:

SD, omitting N

SCD: [COMPONENT] → [SDI, N], where COMPONENT stores components of specifications, COMPONENT.SDI represents the specification id of the specification S of which COMPONENT is a component, and COMPONENT.N is the number of concepts referenced in the component;

- storing the specification inversion as:

SI: [CID] → {COMPONENT}, where CID is a concept identifier and CID.COMPONENT is the set of components referencing the concept identified by CID;

- with K being the set of concepts used to classify document d, for each concept k in K, COMPONENT(k) is the list of components for k (accessible through relation SI) ordered by increasing component id's;
- defining ComponentMergeCount(K) as the set composed of pairs (COMPONENT, N) such that COMPONENT is in ComponentMergeCount(K) if COMPONENT belongs to a COMPONENT(k), k in K; if the pair (COMPONENT, N) is in ComponentMergeCount(K), N counting the number of COMPONENT(k) referencing COMPONENT;
- with S being a set initially empty, for each pair (COMPONENT, N), retrieving COMPONENT.N through relation SCD;
- if COMPONENT.N=N: S=S union COMPONENT.SID, S representing the set of specifications satisfied by d.

67. Process according to Claim 61, wherein the modification of the specification inversion SI comprises the steps of:

- if a specification or component Z references concept C, represented by CID(C) then:
    - if C is a terminal concept:

• CID(C).SID= CID(C).SID union Z, if Z is a specification

- CID(C).COMPONENT= CID(C).COMPONENT union Z, if Z is a component
  - if C is a non-terminal concept:
    * for each k in $C^{down}(C)$
- CID(k).SID= CID(k).SID union Z, if Z is a specification
- CID(k).COMPONENT= CID(k).COMPONENT union Z, if Z is a component.

68. Process according to Claim 61, characterized in that it further comprises computing the specifications satisfied by a set of documents D (whose cardinality is greater than 1) according to the strategy of applying the previous techniques without modifications to every document d in D, then removing possible duplicate specifications.

69. Process according to Claim 61, characterized in that it further comprises computing the specifications satisfied by a set of documents D (whose cardinality is greater than 1) according to a strategy of: defining as K the set of concepts used to classify D; applying the adequate technique among the described ones; and determining the set S of "candidate" specifications, every specification s in S being then checked by performing it on D.

70. Process according to Claim 27, characterized in that the reduced taxonomy is totally computed in a single step, wherein RT is the set of concepts in the reduced taxonomy, RT being computed by testing, for each concept c in T, the membership of { DID } in c through operation AEO3 or AEO4 (if counters are required), concept c being in RT if and only if operation AEO3 returns TRUE or operation AEO4 returns a counter larger than 0.

71. Process according to Claim 70, characterized in that the computation is speeded up through the following steps:

- initializing a table S of size |T|, where S[i] holds information on the current status of concept i, initialized at "pending";
- starting from the uppermost levels, and continuing down in the tree, process concept I;
- if S[i] is "empty", determining that i does not belong to RT, and continuing the processing with the next concept;
- if S[i] is not "empty", applying operation AEO3 or AEO4 to I;
- if the operation returns TRUE (AEO3) or a counter larger than 0 (AEO4), determining that i belongs to RT; otherwise, determining that neither i nor any

of its descendants belong to RT and setting to "empty" all S[j] in S, such that j is a descendant of i in the taxonomy.

72. Process according to Claim 69, characterized in that the descendants are obtained by keeping a precomputed table D, holding for each concept in the taxonomy a list of all the concepts descending from it in the taxonomy, such a table being recomputed every time the taxonomy changes.

Fig. 1